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Engine Fluid Leakage Detection

A Feasibility Study

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Industrial Materials Institute (IMI)
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Technical Memorandum
DRDC Atlantic TM 2011-050
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Abstract

Monitoring any of several parameters improves the ability to detect any potential safety and performance related problems associated with aircraft gas turbine engines. Instant reporting of fuel or engine oil leaks provides engine operators the ability to make judicious decisions as to how the engine should be run under given faulty condition and engine maintains the ability to make timely decisions about engine maintenance. A feasibility study on the use of an ultrasonic based approach to engine fuel or oil leak monitoring is presented. This approach has the potential to be used in real-time applications.

Résumé

Dans une gamme de paramètres, la surveillance d'un seul d'entre eux améliore la capacité de détecter tout problème possible lié à la sécurité ou aux performances des moteurs à turbine à gaz d'aéronefs. Le signalement immédiat d'une fuite de carburant ou d'huile moteur permet aux utilisateurs de prendre des décisions éclairées sur la façon dont le moteur devrait être utilisé compte tenu de sa défectuosité et aux spécialistes de la maintenance de décider rapidement des travaux de maintenance à effectuer. On présente une étude de faisabilité sur l'utilisation d'ultrasons pour surveiller les fuites de carburant ou d'huile moteur. La méthode en question pourrait effectivement être mise en application.

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Executive summary

Engine Fluid Leakage Detection: A Feasibility Study

Nezih Mrad; Zhigang Sun, Kuo-Ting Wu; DRDC Atlantic TM 2011-050; Defence R&D Canada – Atlantic; July 2011.

Introduction or background: Fuel and engine oil leaks not only affect engine performance but can also pose serious threats to the safety of an aircraft, its flight crew and its maintenance staff. Immediate reporting of fuel and engine oil leaks is important for the operator or electronic control system to be able to make judicious decisions as to how the engine should be run under a given faulty condition and for providing critical information to the maintenance crew on the required actions to be taken. The optimal goal of the present work is to develop an innovative approach for real-time monitoring of fuel and engine oil leaks in a flight environment. This work is aimed at exploring a potential waveguide leak detection approach by examining several low footprint waveguide geometries which could be readily implemented.

Results: A feasibility study on the use of an innovative ultrasonic sensing concept is presented. Ultrasonic transducers, thin films, optical fibres and piezoelectric transducers are evaluated for their feasibility using this new concept for monitoring engine fuel and oil leaks. The performance of four waveguide types is presented. All the waveguides were able to sense the presence of oil and fuel. Thin films (stainless steel waveguides) were identified to perform best.

Significance: This feasibility study identified the suitability of an innovative approach to the detection of oil and fuel leaks. This approach has the potential to provide real-time leakage monitoring within an engine environment providing early warning to engine and fleet managers and to enable them to make timely decisions about engine operation.

Future plans: Sensor design with self-diagnosis and self-calibration capabilities and optimization of waveguides in terms of material selection, geometry definition and wave excitation are the next steps in the design of a self-contained device.

Sommaire

Engine Fluid Leakage Detection: A Feasibility Study

Nezih Mrad; Zhigang Sun, Kuo-Ting Wu; DRDC Atlantic TM 2011-050; R & D pour la défense Canada – Atlantique; juillet 2011.

Introduction ou contexte : Les fuites de carburant ou d'huile moteur nuisent non seulement aux performances d'un moteur, mais elles représentent également une menace réelle pour la sécurité de l'aéronef, des membres d'équipage et de l'équipe de maintenance. Il est important qu'une fuite de carburant ou d'huile moteur soit immédiatement signalée à l'utilisateur ou au système de gestion électronique pour que l'on puisse prendre des décisions éclairées sur la façon dont le moteur devrait être utilisé compte tenu de toute défectuosité ainsi que pour donner des renseignements critiques à l'équipe de maintenance sur les mesures à prendre. Le but ultime du présent travail est de développer une méthode innovatrice de surveillance en temps réel des fuites de carburant ou d'huile moteur en vol. Le présent travail vise à étudier une méthode potentielle de détection des fuites par guide d'ondes au moyen de l'analyse de plusieurs géométries de guide d'ondes à faible empreinte qui pourraient être facilement mises en œuvre.

Résultats : On présente une étude de faisabilité sur l'utilisation d'un concept innovateur de capteurs ultrasoniques. On a évalué s'il était possible d'utiliser des transducteurs ultrasoniques, des couches minces, de la fibre optique et des transducteurs piézo-électriques dans le cadre de ce nouveau concept de surveillance des fuites de carburant et d'huile moteur. On présente ainsi les résultats sur l'efficacité de quatre types de guide d'ondes. Tous les guides d'ondes ont été en mesure de relever la présence de carburant ou d'huile. On a établi que les couches minces (guides d'ondes en acier inoxydable) avaient donné les meilleurs résultats.

Importance : La présente étude de faisabilité a permis de déterminer la pertinence d'une méthode innovatrice de détection des fuites d'huile et de carburant. La méthode en question pourrait assurer la surveillance en temps réel de fuites dans un moteur et ainsi alerter rapidement les gestionnaires du moteur et de la flotte, permettant ainsi à ces derniers de prendre des décisions en temps opportun, en fonction de l'état de fonctionnement du moteur.

Perspectives : Les prochaines étapes de conception d'un dispositif autonome consistent à créer un capteur ayant des capacités d'autodiagnostic et d'auto-étalonnage ainsi qu'à mettre au point les guides d'ondes en ce qui concerne la sélection des matériaux, la définition de la géométrie et l'excitation des ondes.

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1 Introduction

Several airframe and engine manufacturers, asset managers and maintainers continue to look at prognostics and health management (PHM) as effective potential approach to reduce maintenance costs, increase platform availability and enhance platform logistics. This concept requires an integrated approach to the acquisition and interpretation of information. As fuel and engine oil leaks not only affect engine performance, but can also pose serious threats to the safety of an aircraft, immediate reporting of fuel and engine oil leaks is important for the operator or electronic control system to be able to make judicious decisions regarding the operation of the engine. This information further assists in the advanced logistics of military platforms and mission execution. The goal of the work is to provide a summary of advances made toward the development of an ultrasonic device for real-time monitoring of fuel and engine oil leaks in a flight environment.

The proposed innovative sensing approach possesses the following features:

a. Large area coverage rather than spot-detection offered by many existing products;

b. Lightweight acoustic waveguide sensing design for negligible weight penalty compared to some much heavier leak detection systems/cables;

c. Applicable to virtually any engine oil/fuel service tubes;

d. High sensitivity to small leak compared to some existing products that require a collection of a minimum of 2 ml or more leaking fluid;

e. Good for engine oil and fuel;

f. Self-diagnosis and self-calibration for reliable sensing; and

g. Reusable or cost effective to replace following a leakage incident.

2 Experimental Setup

The proposed sensing approach uses a waveguide as a sensing element and ultrasonic transducers for generating and receiving ultrasonic waves. In the experimental analysis, the following materials have been explored:

1. ***Glass optical fibres as waveguide***: 9-µm core/125-µm cladding and 62.5-µm core/125-µm cladding provided by Institute for Microstructural Sciences (IMS);

2. ***Plastic optical fibres as waveguide:*** 240-µm core/250-µm cladding, 980-µm core/1000-µm cladding, and 1960-µm core/2000-µm cladding supplied by Edmund Optics.

3. ***Thin film strips as waveguides***: 210-µm thick plastic film supplied by GBC Canada, 170-µm thick paper supplied by 3M, and 25-µm thick stainless shim supplied by Trinity Brand Industries.

1. ***Piezoelectric / Ultrasonic sensors:*** Acellent ¼” smart layer ultrasound transducers (UTs), Panametrics 5-MHz longitudinal wave transducers (V110), and Panametrics 5-MHz shear wave transducers (V156).

Figure 1 illustrates how an ultrasound transducer (e.g. UT) and a sensing waveguide (a strip or fibre) are mounted during a test procedure. An identical transducer setting, not shown in the figure, was utilized on the other end of the sensing waveguide (see Figure 3 for complete view of the setup). By orienting the polarization direction of a shear wave UT, ultrasound excitation in P1 or P3 direction can be selected whereas excitation in P2 direction can be achieved by using a longitudinal UT. In Figure 1, P1, P2 and P3 denote respectively a horizontal direction perpendicular to the sensing strip or fibre principal axis, a horizontal direction parallel to the sensing strip or fibre, and a vertical direction perpendicular to the sensing strip or fibre principal axis. Figure 2 displays the UTs used and Figure 3 illustrates the three sensing setup configurations and the waveguides used.

As an early assessment of the best test set up configuration, several trials were conducted and results showed that for the waveguides explored in this study, propagation of waves excited along the strip or fibre direction was much more efficient than those excited in the other two directions. As a consequence, excitation in the P3 direction was applied in most tests performed. It is also noted that Acellent UTs were able to excite in the P3 direction quite efficiently through the electromechanical coupling in the P3 direction when mounted for P2 direction excitation. This was not the case with other longitudinal UTs used.

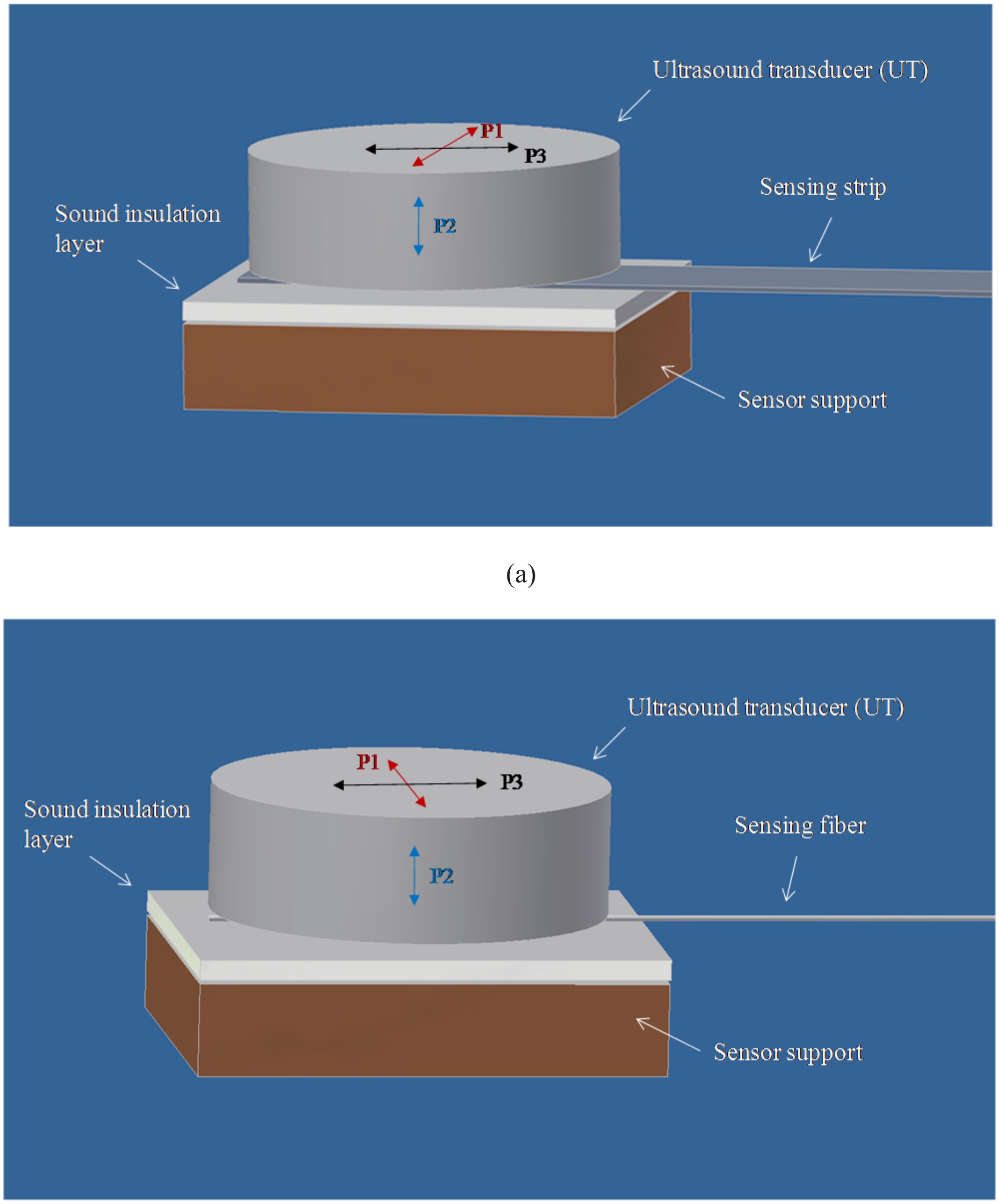

Figure 1: Sensing setup when a sensing strip (a) or a sensing optical fibre (b) is used.

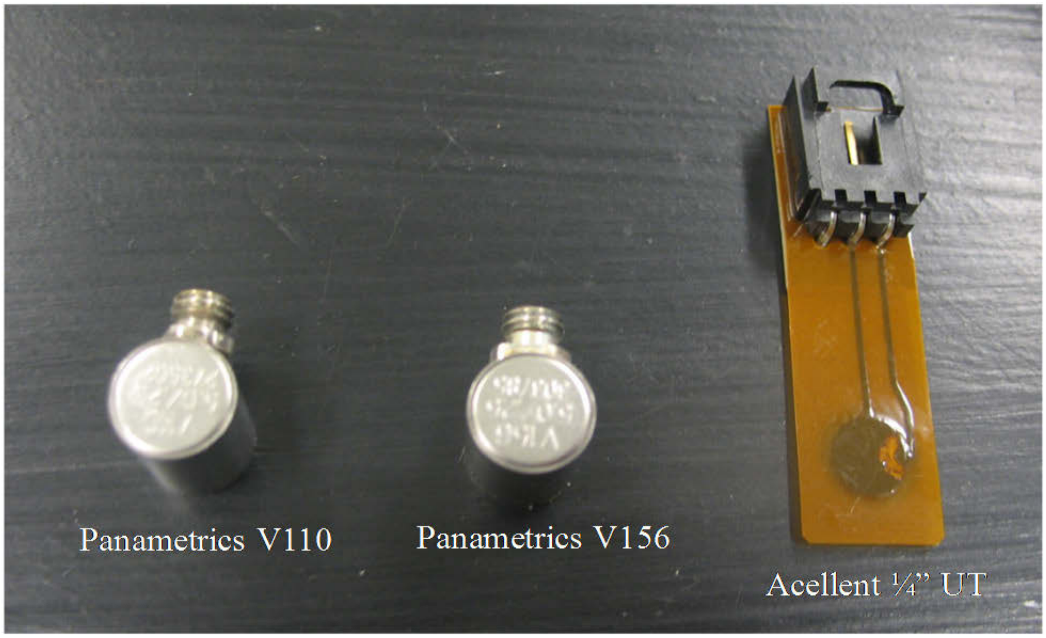

Figure 2: Ultrasound transducers used.

Figure 3: Three sensing configurations.

3 Results and Discussion

Initial tests showed that among all the waveguides explored, the 9-µm core/125-µm cladding glass optical fibre was not able to support ultrasonic waves generated by the transducers used, the 210-µm thick plastic film was much less efficient than the paper and stainless steel strips in propagating acoustic waves, and the 980-µm core/1000-µm cladding and 1960-µm core/2000-µm cladding plastic optical fibres were not as sensitive as their 240-µm core/250-µm cladding counterpart. As a consequence, we only focused on the use of the use of the remaining waveguides:

1. ***Glass optical fibres as waveguide***: 62.5-µm core/125-µm cladding provided by Institute for Microstructural Sciences (IMS);

2. ***Plastic optical fibres as waveguide:*** 240-µm core/250-µm cladding, supplied by Edmund Optics.

3. ***Thin film strips as waveguides***: 170-µm thick paper supplied by 3M, and 25-µm thick stainless shim supplied by Trinity Brand Industries.

A BPTO2380 engine oil and a regular 87 octane gasoline were used as testing fluids. Two Panametrics V156 shear waves transducers polarized in P3 direction were used as sound/ultrasonic emitting and receiving elements, respectively. Figure 4 displays signals propagated through a paper strip waveguide (top), a stainless steel strip waveguide (middle), and glass optical fibre waveguide (bottom). As indicated by the amplification applied, the strongest signal was obtained with the stainless steel (SS) strip (15dB amplification), whereas the signal obtained with the glass optical fibre was the weakest (54dB amplification). In all the cases, multi-trip echoes were observed, meaning that the waveguides were quite efficient in propagating the acoustic waves. In the present document, fluid leak detection with directly transmitted signal is presented while keeping in mind that a multi-trip echo signal may provide a higher sensitivity owing to multiple passes across a waveguide section covered by the fluid of less than 1 mm estimated thickness. It is pointed out that the main focus of this work is aimed at validating quickly the innovative waveguide leak detection approach by exploring several low footprint waveguide geometries which are practical and could be constructed from materials which were readily available. Optimization of waveguides in terms of material selection, geometry definition and wave excitation is the subject of future investigation.

Figure 5 displays directly transmitted signals through a 290-mm long, 7.5-mm wide, and 0.17-mm thick paper strip illustrated in Figure 3 without oil (test 1) and with oil spreads on the strip (tests 2 to 4). It is noted that the same amount of oil was spread from 17 mm to 50 mm extent (Figure 6). As illustrated in Figure 5, the signal amplitude decreases due to dissipation of acoustic energy into the oil. The signal strength decreases with an increase in the size of oil spread. This was expected as a larger oil spread means that the diagnostic wave has more chance to leak into the surrounding fluid. In addition, the arrival time of the signal also increases with the oil spread.

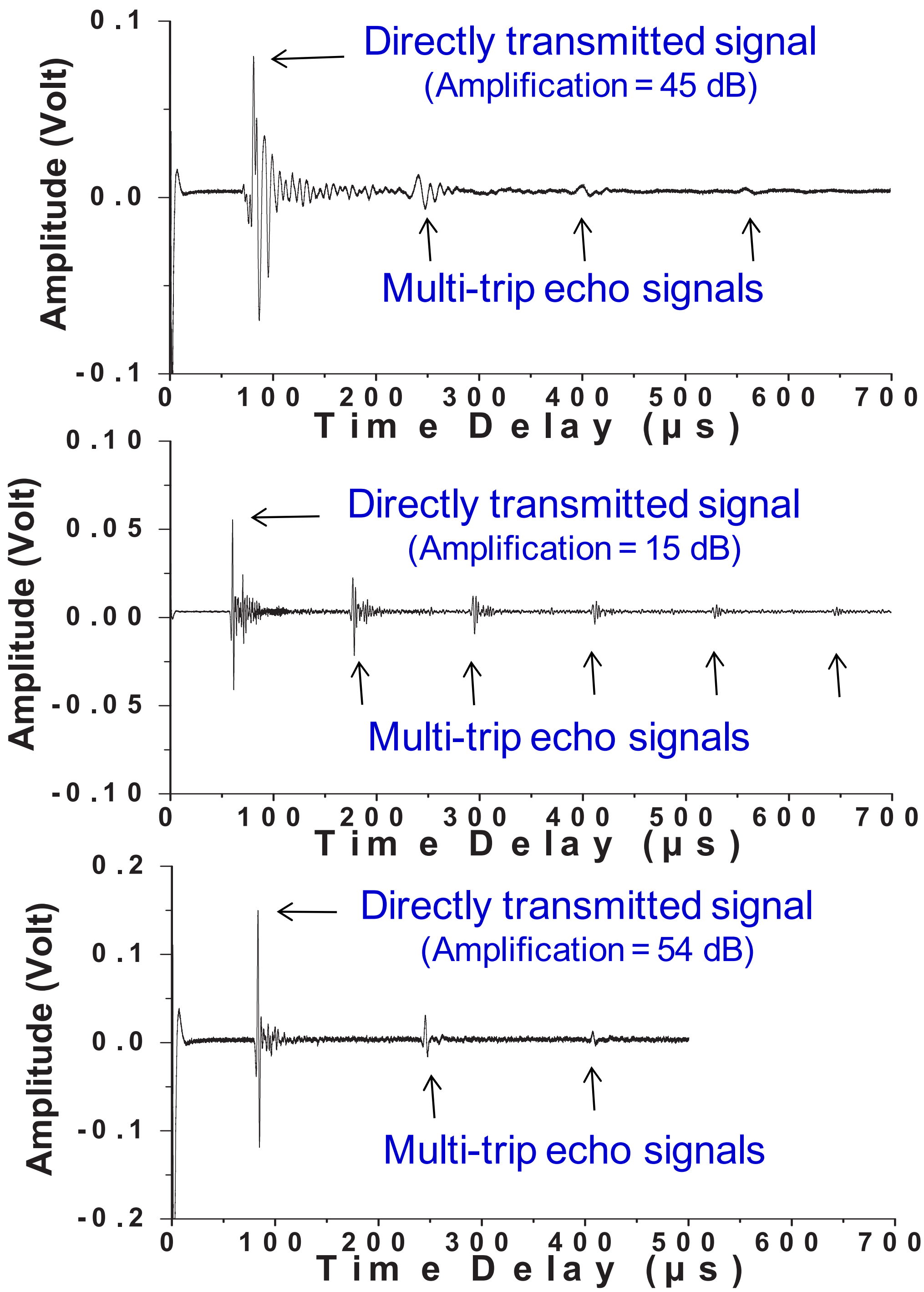

Figure 4: Signals propagated through a 290-mm long paper strip at 45 dB amplification (top), a 290-mm long SS strip at 15 dB amplification (middle), and a 310-mm long glass optical fibre at 54 dB amplification (bottom).

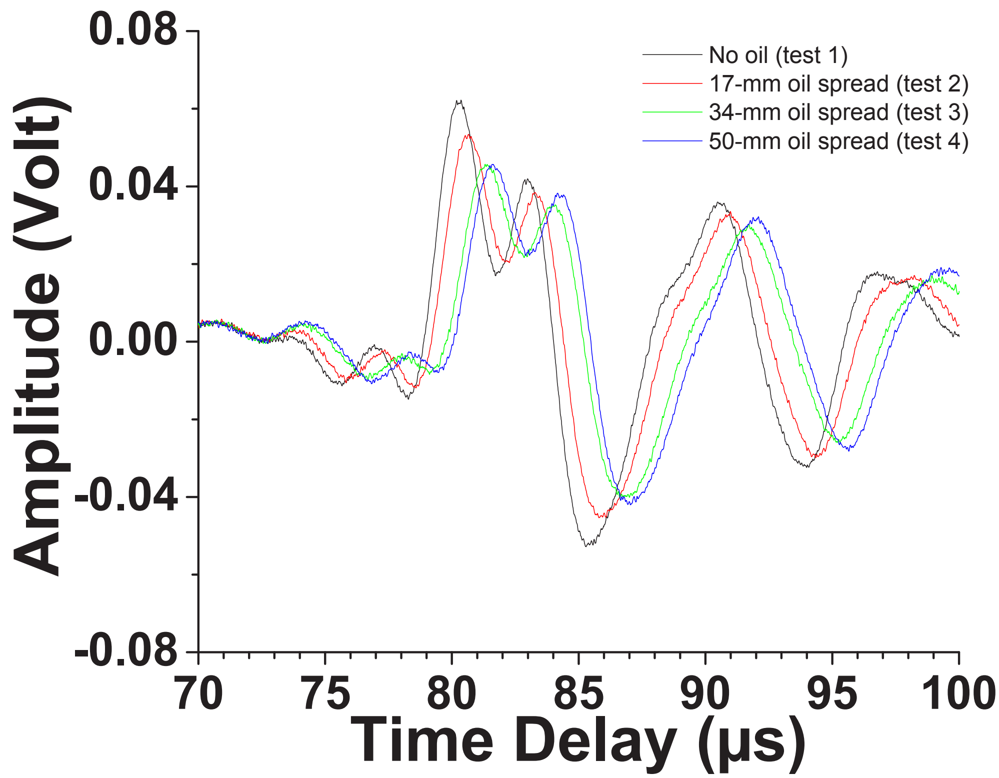

Figure 5: Oil sensing results by using a 290-mm long paper strip.

Figure 6: Oil sensing results by using a 290-mm long paper strip (different spread: 17, 34, 50 mm).

Figure 7 displays directly transmitted signals through a 290-mm long, 7.5-mm wide, and 0.17-mm thick paper strip (see middle plot in Figure 3) in the presence of fuel stain. In the first test (test 1), no fuel was used; however, in the subsequent test, a drop of fuel was placed on the paper strip. The fuel was absorbed right away by the paper to form a 37-mm length fuel stain. A signal recorded right after the fuel stain was formed (test 2). Compared with test 1, noticeable amplitude decrease and arrival time increase of the signal are observed. Forty minutes later, the signal of test 3, almost recovered to its initial state due to evaporation of the fuel. The signal recorded at sixty minutes into the test (test 4) does not differ noticeably from that of test 3, meaning that at 40 minutes; the fuel was already evaporated almost completely. The difference between test 4 (or 3) and test 1 signals is believed to be caused by the fuel residue slightly discernable in Figure 8.

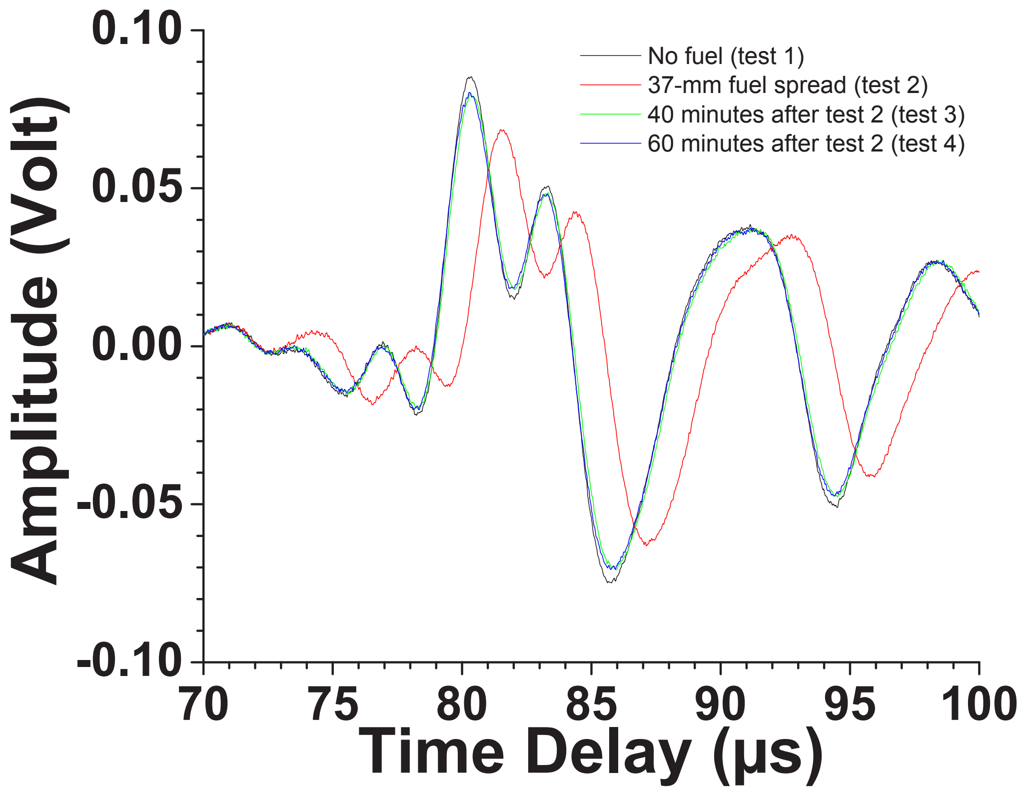

Figure 7: Fuel sensing results by using a 290-mm long paper strip.

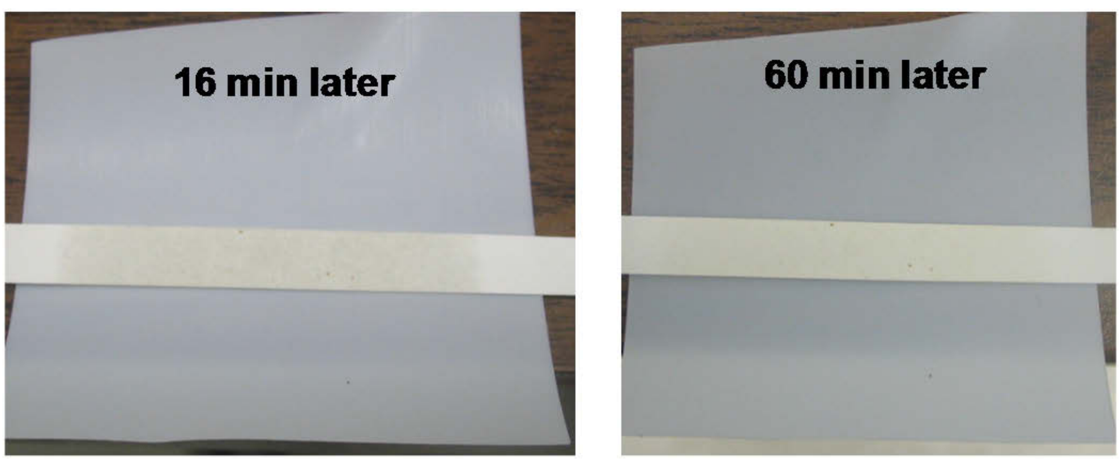

Figure 8: Fuel stain at 16 minutes (left) and 60 minutes (right) after a drop of fuel was dropped on a paper strip.

The paper strip tested was also sensitive to water. Figure 9 shows some tests results. Particular attention is drawn to test 5 in which the signal amplitude came back strong after evaporation of a certain amount of water.

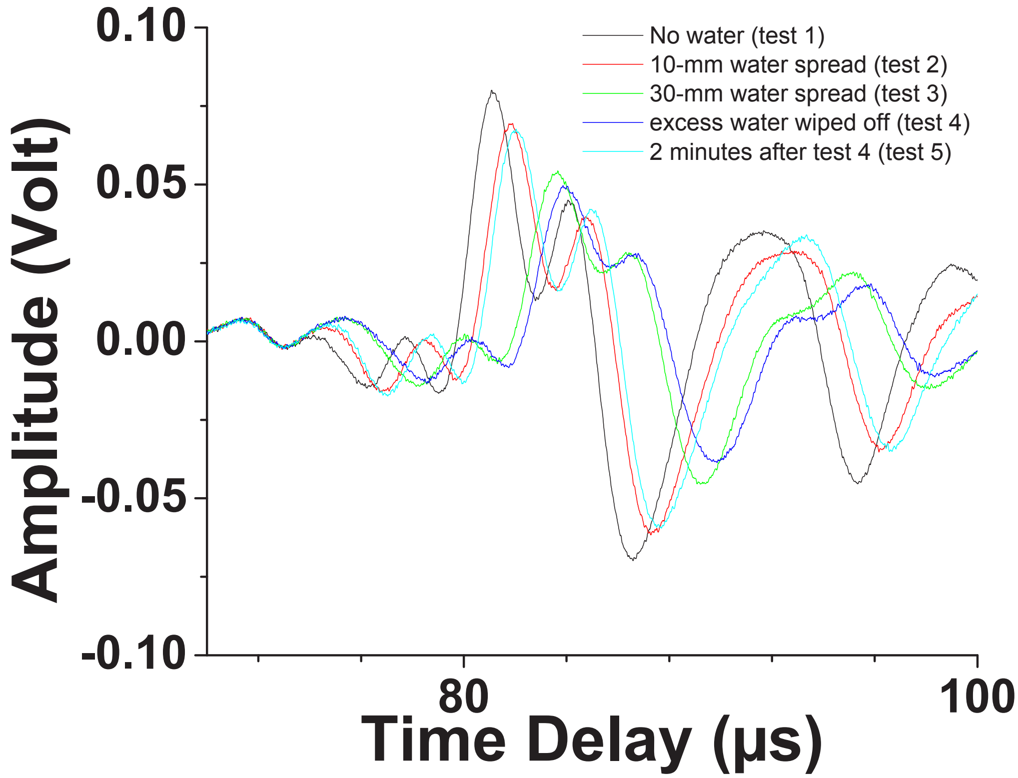

Figure 9: Water sensing results by using a 290-mm long paper strip.

Figure 10 displays directly transmitted signals through a 290-mm long, 2-mm wide, and 25-μm thick Stainless Steel (SS) strip, illustrated in Figure 3, without oil (test 1) and with oil spreads on the strip (tests 2 to 3). Decrease in signal amplitude was observed with increasing amount of oil spread on the strip. In this preliminary study, there has been no attempt to quantity the effect of oil thickness on signal amplitude. However, it is believed that for a given amount of oil, the extent of oil spread should have more effect on signal amplitude than oil thickness because a larger contact area between the waveguide and oil will facilitate leakage of ultrasound energy from the waveguide into the oil. Figure 11 shows fuel sensing results obtained by using the same SS strip. With the presence of fuel (test 2), the signal amplitude dropped slightly. After fuel evaporated (test 3), the signal amplitude came back to initial value observed in test 1. Although the SS strip seems to be less sensitive than the paper strip to oil and fuel, it has the advantages of being reusable by simply wiping off oil or fuel residue following a leak incident.

Figure 12 displays directly transmitted signals through a 62.5-μm core/125-μm cladding and 290-mm long glass optical fibre in absence of oil (tests 1 and 4) and in presence of oil (tests 2 and 3). In the case of tests 2 and 3, a droplet of oil was applied to the fibre using a pipet. Figure 13 shows directly transmitted signals through a slightly shorter glass optical fibre (280-mm) of the same type without fuel (test 1) and in presence of fuel (tests 2 an 3). It should be pointed out that the length of fibre will affect sensing sensitivity in terms of both signal amplitude and signal arrival time. Intuitively, the sensing sensitivity should increase with increase in oil spread to waveguide length ratio.

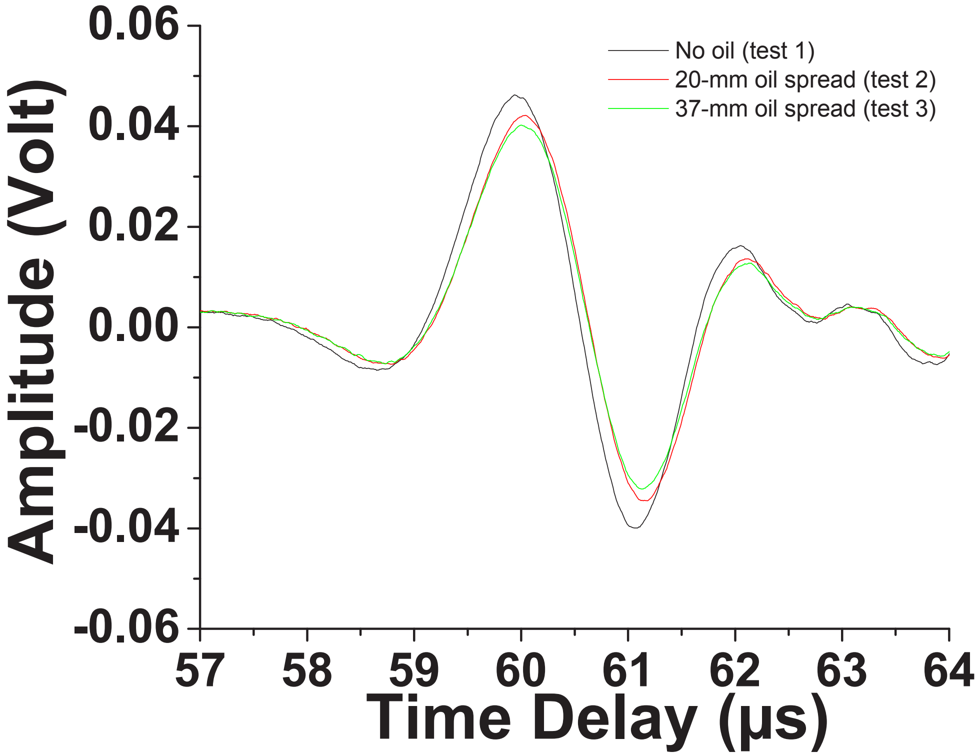

Figure 10: Oil sensing results by using a 290-mm long stainless steel strip.

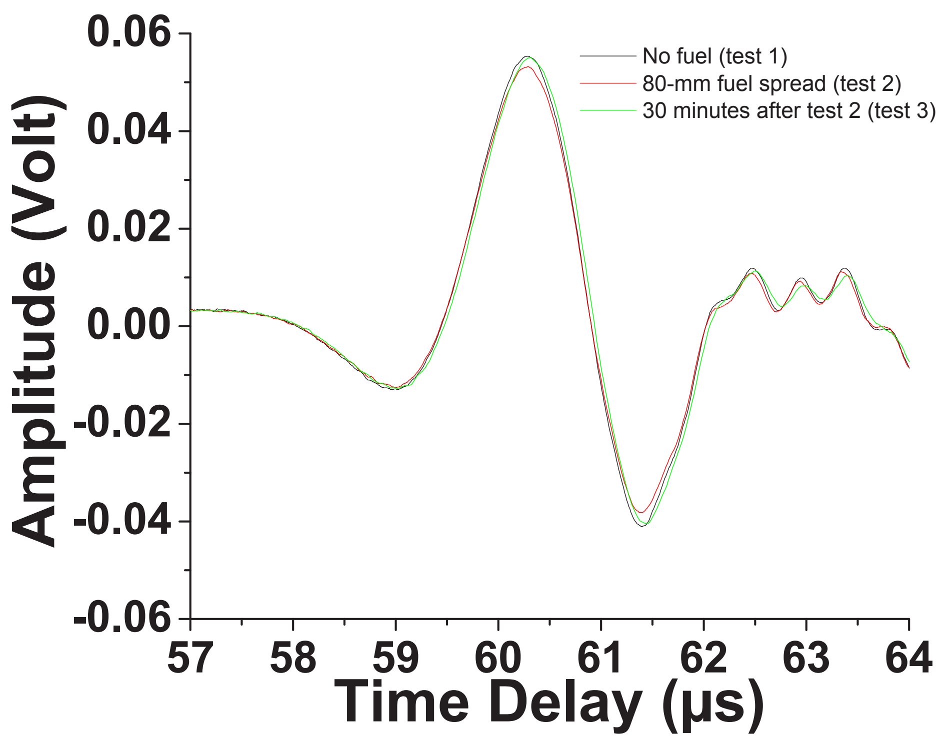

Figure 11: Fuel sensing results by using a 290-mm long stainless steel strip.

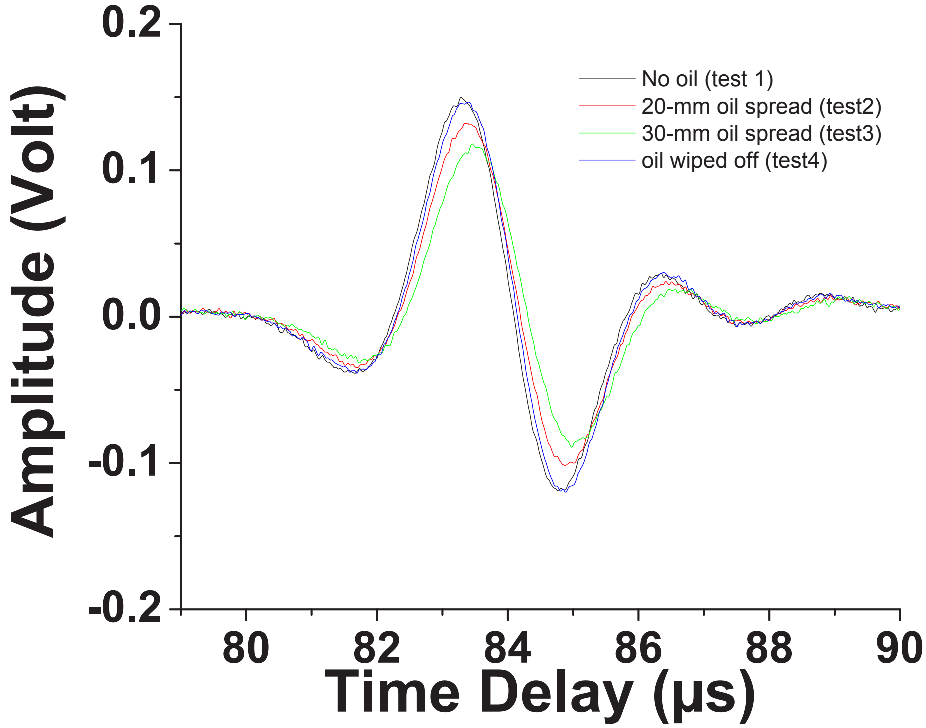

Figure 12: Oil sensing results by using a 290-mm long glass optic fibre.

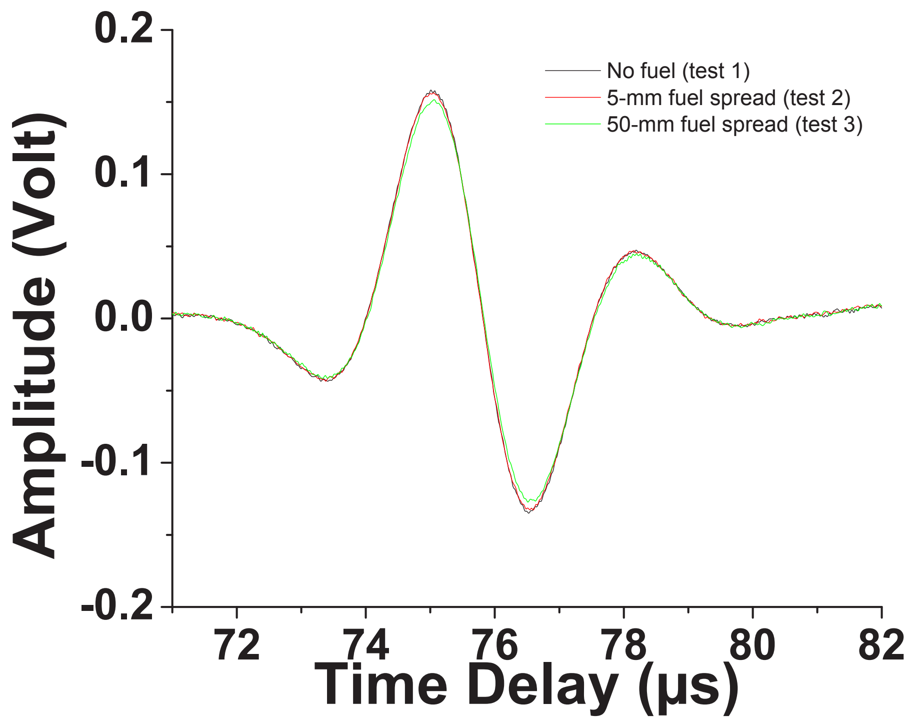

Figure 13: Fuel sensing results by using a 280-mm long glass optic fibre.

Both SS strip and glass optic fibre appear to be more sensitive to oil than to fuel. We believe this difference in sensitivities to oil and fuel originates in the difference in acoustic impedances of the two fluids. To confirm this hypothesis, acoustic impedance measurements need to be conducted for the two fluids.

While the glass optical fibre seems to have similar sensitivity to oil as compared to the paper strip, it has the advantages of being reusable by simply wiping off oil residue following a leak incident and resistant to humidity (i.e., not sensitive to the presence of water as revealed by our tests). However, the excitation and reception of acoustic waves in the fibre were less efficient due to its much smaller contact areas with the transducers.

Figure 14 displays directly transmitted signals through a 100-mm long, 240-µm core/250-µm cladding plastic optical fibre in absence of oil (test 1) and in presence of oil (tests 2 and 3). Because there is a large acoustic attenuation in plastic fibres, a much shorter fibre was used. Good sensitivity of this fibre to the presence of oil is observed. Except for this weaker signal strength, the plastic optical fibre enjoys all other benefits of the glass optical fibre presented earlier and can be used to cover a small area. Tests of the sensitivity of the plastic optical fibre to fuel will be conducted later.

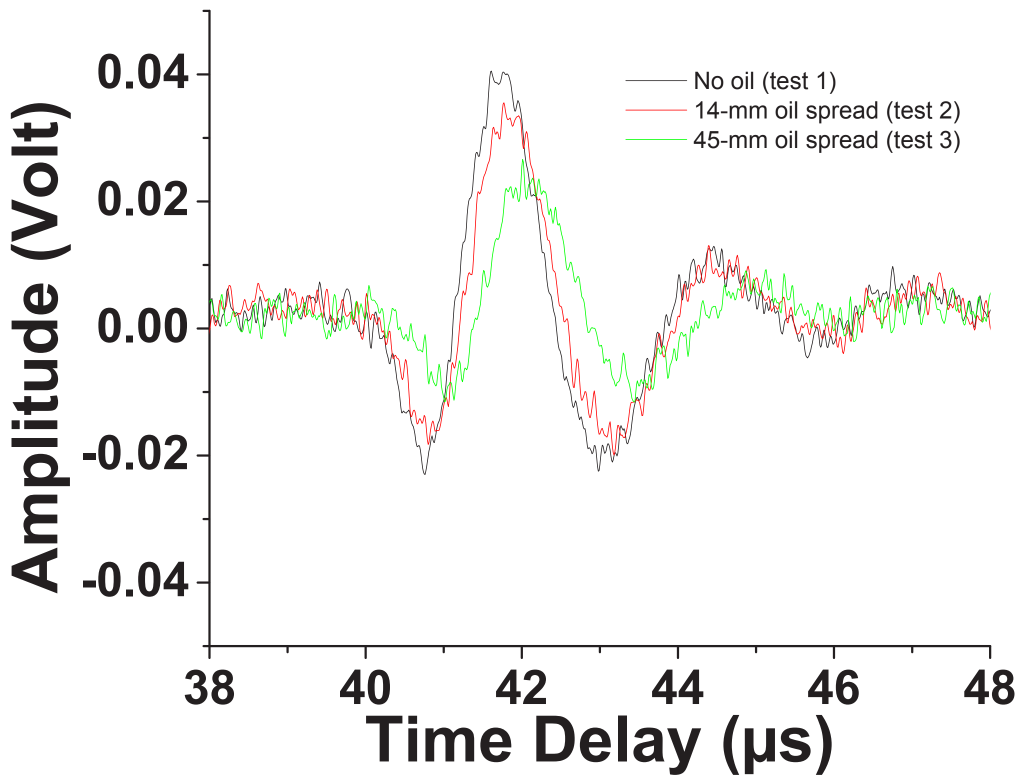

Figure 14: Oil sensing results by using a 100-mm long plastic optical fibre at 54 dB amplification.

Finally, it is observed that the sensitivity of a waveguide to a fluid of which the leak is to be detected depends strongly on the wetness of the waveguide material. It may be desirable and possible to select or custom-make a waveguide material in such a way that it is selectively sensitive to certain fluids while insensitive to other fluids to reduce the chance of false alarms. While the stainless (SS) strip and the optical fibres were more or less sensitive to the presence of oil and fuel, they didn't show noticeable sensitivity to water. This difference in sensitivities is understandable by examining three wetness tests results shown in Figure 15. Obviously, the better a waveguide is wetted by a fluid, the easier it is for acoustic waves to propagate from the waveguide to the fluid, and, as a consequence, the higher is the sensitivity of the waveguide to the presence of this fluid. In addition to wetness, the acoustic impedance mismatch between the waveguide and the fluid can affect the waveguide sensitivity as well, as discussed earlier.

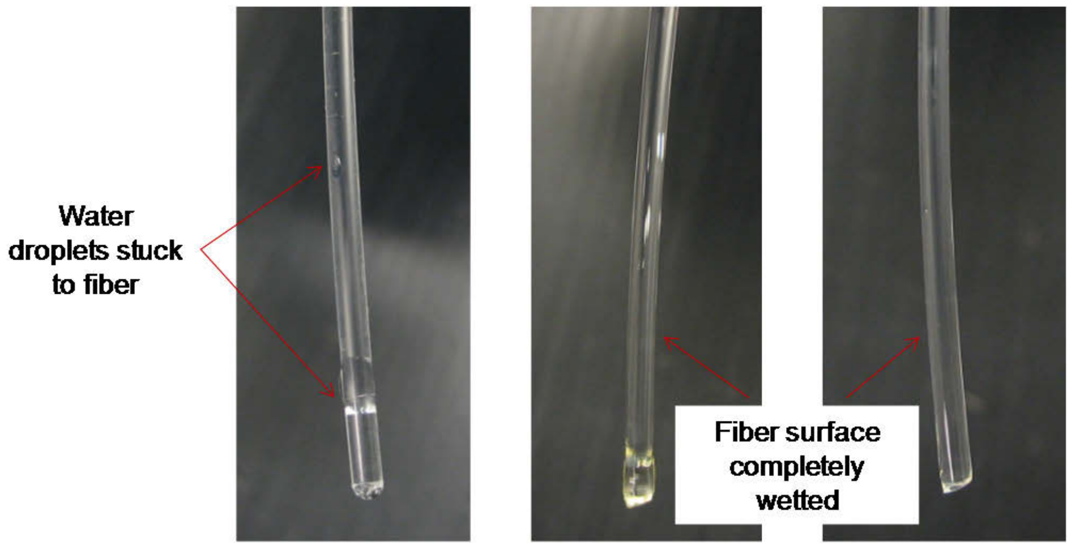

Figure 15: Wetness tests of a 2-mm diameter plastic optical fibre by water (left), oil (middle) and fuel (right). Only a tiny amount of water was able to stick to the fibre whereas the oil and fuel were able to wet the entire fibre surfaces.

It is highlighted that the effect of fluid thickness is not investigated in this work but will be the subject of future activity.

4 Conclusions

An acoustic waveguide based approach for fluid (oil and fuel) leak detection has been defined and evaluated. The performance of four types of waveguides was presented. All waveguides were able to sense the presence of oil and fuel. Since each type of waveguide has its own advantages and disadvantages, the choice of waveguide will depend on the targeted application and the operating environment it is intended for. For the future direction, a design of sensors with self-diagnosis/self-calibration capabilities incorporating a reference wave path (or signal) to the sensing circuitry and integrating ultrasound transducers to waveguides will be investigated.

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Monitoring any of several parameters, improves the ability to detect any potential safety and performance related problems associated with aircraft gas turbine engines. Immediate reporting of fuel or engine oil leaks provides engine operators the ability to make judicious decisions as to how the engine should be run under given faulty condition and engine maintainer the ability to make timely decision of the engine maintenance. A feasibility study on the use of an ultrasonic based approach to engine fuel or oil leak monitoring is presented. This approach has the potential to be used in real-time applications.

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